Int J Life Cycle Assess (2014) 19:1276–1293
DOI 10.1007/s11367-014-0737-y

Environmental assessment of Peruvian *anchoveta* food products: is less refined better?

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Received: 16 November 2013 / Accepted: 19 March 2014 / Published online: 13 April 2014

Abstract
Purpose Life cycle assessments (LCAs) of various anchovy (*anchoveta*) direct human consumption products processed in Peru were carried out, to evaluate their relative environmental performance as alternative products to enhance nutrition of communities with low access to fish products in the country.
Methods LCA was carried out for fresh, frozen, canned, salted and cured anchoveta products, both at plant gate and featuring local and national distribution over non-refrigerated, chilled and fully refrigerated distribution chain. The functional unit used was 1 kg of fish in the final product.
Results and discussion Results demonstrate that, in environmental terms, more-refined products (cured and canned *anchoveta* products) represent a much higher burden than less- refined products (fresh, frozen and salted). Although this is a likely result, the magnitude of this difference (4 to 27 times when expressed as an environmental single score) is higher than expected and had not been quantified before for salted and cured products, as far as we know. This difference is mainly due to differences in energy consumption between types of products. Furthermore, cured and salted products feature larger biotic resource use, when calculated based on the whole fish equivalent, due to higher processing losses/ discards. The relevance of taking into account the different transportation and storage needs is highlighted. For those products requiring refrigerated transportation and storage, over a national distribution chain, those activities increase the overall environmental impacts of the products by 55 % (fresh chilled) to 67 % (frozen). However, such an increase does not worsen the environmental performance of fresh and frozen products in comparison to the energy-intensive canned and cured products.
Conclusions It is concluded that a more sustainability-oriented analysis, including the social and economic pillars of sustainability, is required towards decision-making involving promotion of either product for addressing nutritional deficiencies in Peru.

Keywords Cold chain · *Engraulis ringens* · Frozen, canned and cured fish · Life cycle assessment · Peru

Responsible editor: Mary Ann Curran

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1 Introduction

The Peruvian *anchoveta* (*Engraulis ringens*) fishery is one of the most important ones in the world, in terms of landings and its relation with global animal feed industries (SOFIA 2012). The anchoveta purse seiner fleet encompasses both an industrial fleet and a small- and medium-scale (SMS) fleet (Avadí et al. 2014; Fréon et al. 2013, 2014a, b). The industrial fleet lands fish for reduction, referred to in Peru as indirect human consumption (IHC), whereas the SMS fleet lands fish for both IHC (illegally) and food, referred to in Peru as direct human consumption (DHC). Additionally, the SMS fleet has exclusive access to specific fishing grounds, namely the first five nautical miles for the SS fleet and between the first five and ten nautical miles for the MS fleet (Supreme Decree 005-2012-PRODUCE, although a recent Supreme Court Decree

declared it unconstitutional). Including all fleets, total landing volumes average 6 to 7 million tonnes/year (PRODUCE 2012a), of which around 98 % is destined to the fishmeal and fish oil (FMFO) industry, and the remaining less than 2 % is processed into human food products (Fréon et al. 2010, 2013).

The Peruvian population surpasses 27 million inhabitants, of which more than 70 % live in urban areas. Poverty, defined as the incapacity to meet the basic household needs (food, healthcare and education), is roughly equivalent to the lowest quintile of income, expenditures and assets (INEI 2012a). It reaches 60 % in the rural areas (especially in the Andean and Amazonian regions) and ~3 % in urban areas (INEI 2011, 2012a). Hunger is clearly associated to poverty (FAO 2011). According to FAO and the Global Hunger Index (FAO 2000; IFPRI 2006, 2012), Peru has advanced in hunger reduction, yet continues being one of the few Latin-American countries featuring moderate hunger. In some Andean regions, where the most economically depressed communities in Peru are located, indicators such as chronic malnutrition of children under five years old, stunting and undernourishment are still high (FAO 2000, 2011; INEI 2011). Given such situation, Peruvian government policies have historically been, to some extent, oriented to provide vulnerable communities with cheap sources of animal protein and in general improve access to nutritious food. Several voices in Peru have discussed the need for stimulating consumption of anchoveta products, and consequently both government and private initiatives have tackled the issue (PRODUCE 2012b), yet without notable results (Sánchez and Gallo 2009).[1] Annual per capita fish consumption average was estimated in ~20 kg in 2005–2011 (INEI 2012b) but less than 12 % of this amount is anchoveta. Moreover, 9 % of fish products consumed in Peru (mainly canned products) are imported (del Carpio and Vila 2010). The estimated national consumption and exports of anchoveta products is listed in Table 1. Despite its recent increase, anchoveta consumption is still minimal yet it represents in average approximately 70 % of anchoveta production for DHC. The consumption of fresh anchoveta, despite being marginal and displaying a decreasing trend (Table 1), was included for completion and towards consideration of future increased consumption. The consumption of the other anchoveta DHC products shows an increasing trend (2006–2010), especially canned products with an average annual increase of 149 %.

[1] A typical example is the National Programme of Food Assistance (Programa Nacional de Asistencia Alimentaria - PRONAA), which ran from 1992 to 2012 and purchased large volumes of *anchoveta* and jumbo squid (*Dosidicus gigas*) DHC products to make them available to the population at subsidised prices. Eventually, PRONAA faced a number of criticisms related to poor management and performance, low quality of food, corruption, etc. (Paredes 2013) and was transferred to regional bodies (Supreme Decree 007-2012-MIDIS).

There is a variety of policy and market interventions that could be deployed to tackle protein deficiency and malnourishment in general of vulnerable Peruvian communities. Nonetheless, it seems natural that given the huge stock of a cheap source of fish protein and fatty acids available to Peru, scientific, policy and lobbying efforts have focused on promoting the DHC of anchoveta (e.g. CSA-UPCH 2012; de la Puente et al. 2011; OANNES 2012; Rokovich 2009). Indeed seafood (including aquaculture products) derived from the anchoveta supply chains, has been often suggested as a suitable means to improve nutritional intake of vulnerable communities and consumers at large (Jiménez and Gómez 2005; Rokovich 2009; De la Puente et al. 2011; Landa 2012; Paredes 2012). The Peruvian population at large would benefit from a greater availability of anchoveta DHC products, due to their important nutritional features: high contents of gross energy, protein, fatty acids, vitamins and minerals, in comparison to other fish products available in Peru (Avadí and Fréon 2014). Research efforts should thus address the scientific aspects to evaluate the environmental performance and other sustainability metrics of the different anchoveta DHC supply chains.

This study introduces a life cycle assessment (LCA) of anchoveta products for DHC. Given their relevance in the Peruvian fish processing industry, and the abovementioned intent of promoting national consumption of anchoveta products, we focused on the more representative processing industries in Peru: canning, freezing and curing.

Anchoveta frozen products are mostly consumed in the country (as opposite to other species frozen products, which are to a large extent exported), while canned products are both exported and consumed in Peru (del Carpio and Vila 2010; PROMPERU 2011). As of 2011, installed capacities of whole fish by processing plants were roughly as follows, according to official statistics (PRODUCE 2012a; INEI 2012b): freezing, 2.4 million t a^{-1} in 117 plants; curing, 1.3 million t a^{-1} in 18 plants; and canning,[2] 720,000 t a^{-1} in 69 plants.

Fresh anchoveta is available almost exclusively at landing points. According to current legislation, vessels landing anchoveta for DHC must have a purchase agreement with a processing plant (Ministerial Resolution 433-2012-PRODUCE). That is to say, fishers cannot sell their catch directly for fresh consumption. Moreover, most landing facilities for DHC fail to fulfil the requirements set by the sanitary standard for fisheries and aquaculture resources (Supreme Decree 040-2001-PE; Rokovich 2009). The lack of a cold chain for fish in Peru is a major limiting factor for the further

[2] Processing capacity of the canning industry is published in terms of boxes per time period, without further detailing of the canned product presentation or fish species. The figure proposed was calculated for the case of *anchoveta* processed into 1/4 club cans (net weight, 125 g; fish, 90 g; and overall process losses of fish, ~60 %), following data provided by the Peruvian Institute for Fish Technology (ITP 2012).

Table 1 Estimation of the national consumption of *anchoveta* DHC products, in fresh fish equivalents (2006–2010)

	2006	2007	2008	2009	2010	Average	Contribution (%)
Estimated national consumption (t)							
Canned	18,700	45,844	58,051	62,557	72,634	51,557	58
Frozen	68	2,486	7,332	9,517	11,693	6,219	7
Fresh	538	401	336	293	223	358	<1
Salted	6,058	1,459	942	2,962	3,979	3,080	3.5
Subtotal	25,363	50,190	66,660	75,329	88,529	61,214	
Estimated exports (t)							
Canned	12,319	16,112	20,800	22,416	21,613	18,652	21
Frozen	1,210	2,800	4,933	2,010	3,467	2,884	3
Cured and salted	4,610	6,000	6,200	6,810	6,600	6,044	7
Subtotal	18,139	24,912	31,933	31,236	31,680	27,580	
Anchoveta total for DHC (t)	43,502	75,102	98,594	106,565	120,209	88,794	100
Anchoveta for IHC (t)	5,891,800	6,084,700	6,159,387	5,828,600	3,330,400	5,458,977	

Notes: National consumption was estimated by deducting PROMPERU export statistics from RECIPE landings statistics. The following conversion factors with respect to fresh fish were used: canned=0.50, frozen=0.75 and cured=0.25; the use of these factors reflects the different initial processes displayed in Figs. 1 and 2. Conversion factors are based on industrial yields of the different industries studied and in personal communication with a Peruvian analyst on anchoveta fisheries and industries (Sueiro, personal communication, 2012). Source: PRODUCE (2012a) statistics and PROMPERU (2010)

development of domestic distribution channels, especially for such a delicate fish as anchoveta.

Existing distributions chains for fresh and frozen fish in Peru (cold chain) are clearly insufficient to deliver fresh, chilled and frozen fish and fish products to the national population outside the main coastal urban areas (Sueiro 2006; del Carpio and Vila 2010). Only the coastal, especially urban areas such as Lima and other big cities are well provided of fresh marine fish. The Amazon regions also have a steady supply of (freshwater) fish, as to lesser extent do the highland regions close to water bodies where trout and native fish are cultured and wild caught, as can be discerned from consumption statistics (INEI 2012c). Few studies have analysed the distribution of fish in Peru (e.g. del Carpio and Vila 2010; Rokovich 2009; Sanguinetti 2010a, b, c, d; Sanguinetti 2009; Sueiro 2006). From these reports, the distribution chain for fish can be summarised as a combination of (a) wholesaler markets concentrating the distribution of fresh fish, providing retailers, markets and supermarkets, restaurants etc.; (b) processing plants and importers of canned, frozen and salted fish products distributing to retailers, markets and supermarkets; and (c) distribution chains. Only canned products feature national distribution (non-refrigerated), whereas other types of products are distributed mainly locally, or in some cases by airfare, in very small amounts.

We performed LCAs of different anchoveta products and interpreted the results to suggest directions for further development of those industries, as a tool for contributing to the sustainable development of those industries. We placed emphasis on the potential of the different products to contribute in an environmentally sound way to improve nutrition of the population.

2 Methods

2.1 Goal and scope

LCA is an ISO-standardised framework for conducting a detailed account of all resources consumed and emissions associated to a specific product along its whole life cycle (ISO 2006a). LCA has been widely applied to study the environmental performance of fisheries and aquaculture products, both fresh and processed (Hospido et al. 2006; Iribarren et al. 2010; Henriksson et al. 2011; Parker 2012; Vázquez-Rowe et al. 2012a; Avadí and Fréon 2013). LCA consists of a goal and scope definition phase, where the functional unit (FU) and system boundary are defined; a life cycle inventory (LCI) phase, where life cycle data related to the FU is collected; a life cycle impact assessment (LCIA) phase where a set of characterisation factors are used to calculate environmental impacts on a wide number of impact categories, and an interpretation phase, where conclusions are drawn from the LCI and LCIA results (ISO 2006a, b).

Figure 1 depicts simplified process flows for three different anchoveta DHC product, whereas a value chain diagram of the anchoveta DHC industry in Peru is depicted in Fig. 2. It should be noticed that, in the curing value chain, products from the intermediate step “Salting” are consumed in Peru,

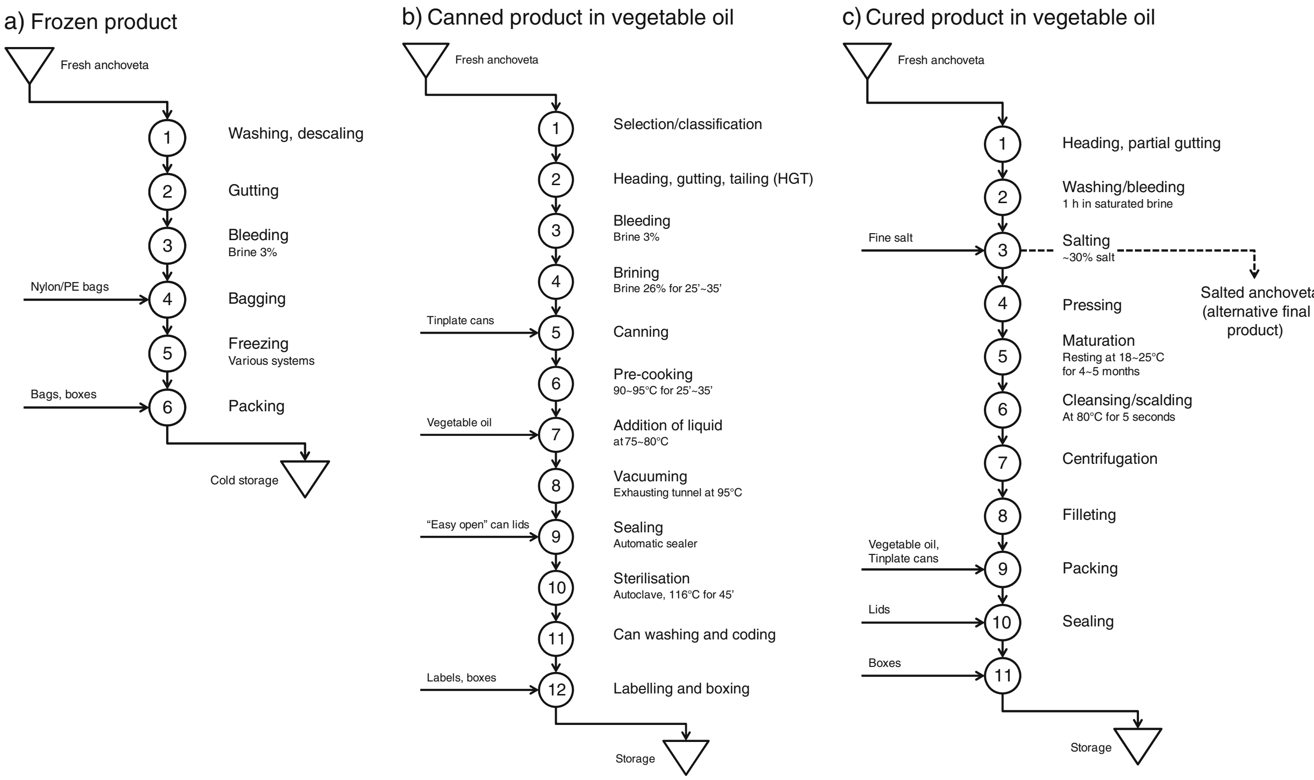
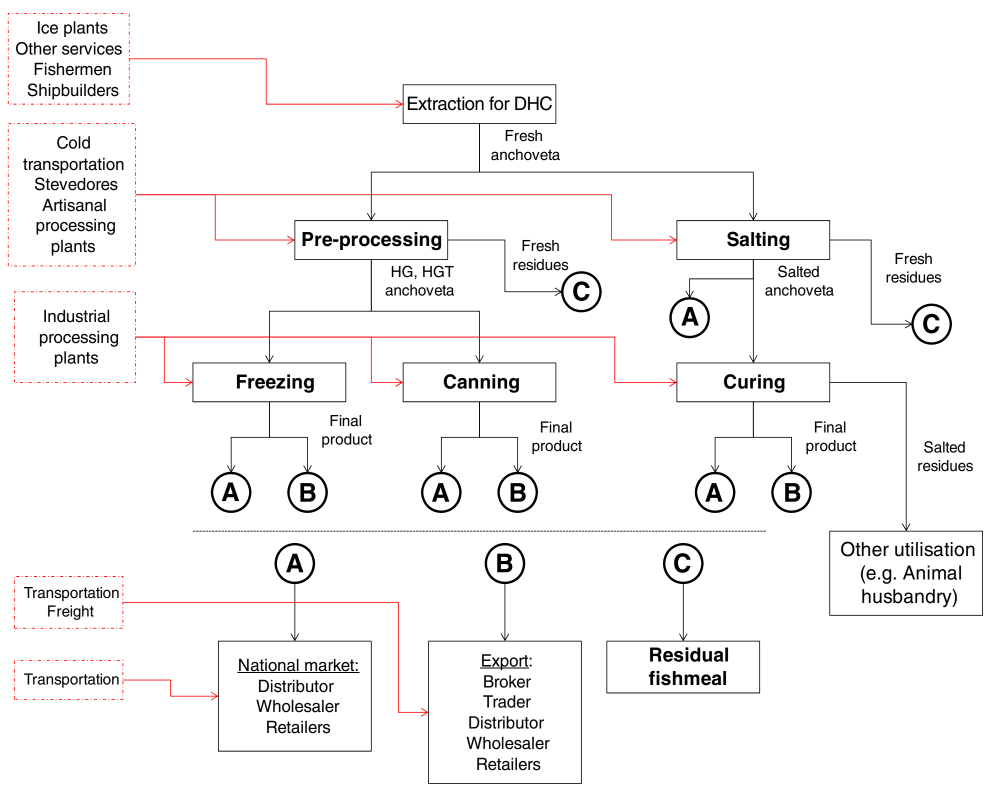


Fig. 1 Simplified flow diagrams of three anchoveta DHC products. Source: based on ITP technical sheets (ITP 2007), Pablo Echevarría (Compañía Americana de Conservas, personal communication, Mar 2013) and (PENX 2004)

Fig. 2 The Peruvian *anchoveta* processing industry value chain. Sources: ITP (2007), Pablo Echevarría (Compañía Americana de Conservas, personal communication, Mar 2013) and PENX (2004)



whereas the final cured products (packaged in vacuum bags, cans or glass containers) are currently exported.

The following systems were modelled: an anchoveta canning plant, a fish freezing plant and an anchoveta curing plant. Anchoveta landed for DHC, without processing, was modelled as fresh fish for immediate consumption. System boundaries of the study, as shown in Fig. 3, include the pre-processing of fish (gutting, heading and cleaning), the Peruvian electricity mix and the fish processing processes. System boundaries also include the operations of the SMS wooden fleet landing anchoveta for DHC. Detailed analyses of the SMS fleet, in comparison with the industrial fleets, are presented in Fréon et al. (2014b) and Avadí et al. (2014). Transport from plants to retailers and from retailers to consumer, as well as intermediate storage, are usually excluded from the perimeter in sea-to-gate LCAs, and no inventory data was collected in this study. Nonetheless, due to the expected large differences in the impacts of transport of the different categories of DHC products, even at national scale, we performed a screening-level LCAs of distribution. We estimated from literature the comparative contribution to impacts of the existing distribution chain for fish in Peru and of a simulated distribution chain, extended to the interior of the country. Such a comparison is aimed at suggesting future directions for the currently marginal market for fresh anchoveta (and fresh fish in general). We modelled the existing distribution chain as local (when only serving the coastal region) and national (when serving the whole country), both of which can be non-refrigerated, chilled or fully refrigerated. The extended distribution chain was modelled as national, also non-refrigerated, chilled or fully refrigerated depending on the needs of distributed products.

The FU was defined as 1 kg (t) of anchoveta DHC product, referred to in this study as “1 kg of fish in product”. Such a FU was chosen to normalise the differences in discards, process losses and residues, and thus in the ratio final product/raw material among manufacturing processes. The FU includes edible fish (flesh and bones) and accounts for dehydration of the fish carcass during the processing. Residues were assumed to substitute fresh anchoveta landed for reduction (duly affected by the conversion ratios residues/fishmeal and fresh anchoveta/fishmeal). Consequently, mass allocation was applied between residues and processed fish, given similar gross energy contents and the fact that both whole anchoveta and its residues are used for reduction. The revalorisation of residues (i.e. by residual fishmeal plants) lowers the overall impacts of DHC products, as a function of the amount of residues generated, which varies considerably among them. Moreover, this selection of FU is consistent with previous research (e.g. Hospido et al. 2006). The reference flow for each DHC process was thus the amount of anchoveta entering each process, including associated discards, processing residues and process losses due to transformation. The FU excludes packaging and other product materials (e.g. vegetable oils).

The reference flow represents the “usable” fraction of catches which is nominally landed for DHC and that actually reaches a DHC process. The usable fraction has been estimated to be 10 to 50 % of DHC landings according to the final product, whereas the balance is diverted to reduction plants. Illegal, unreported and unregulated (IUU) landings have been

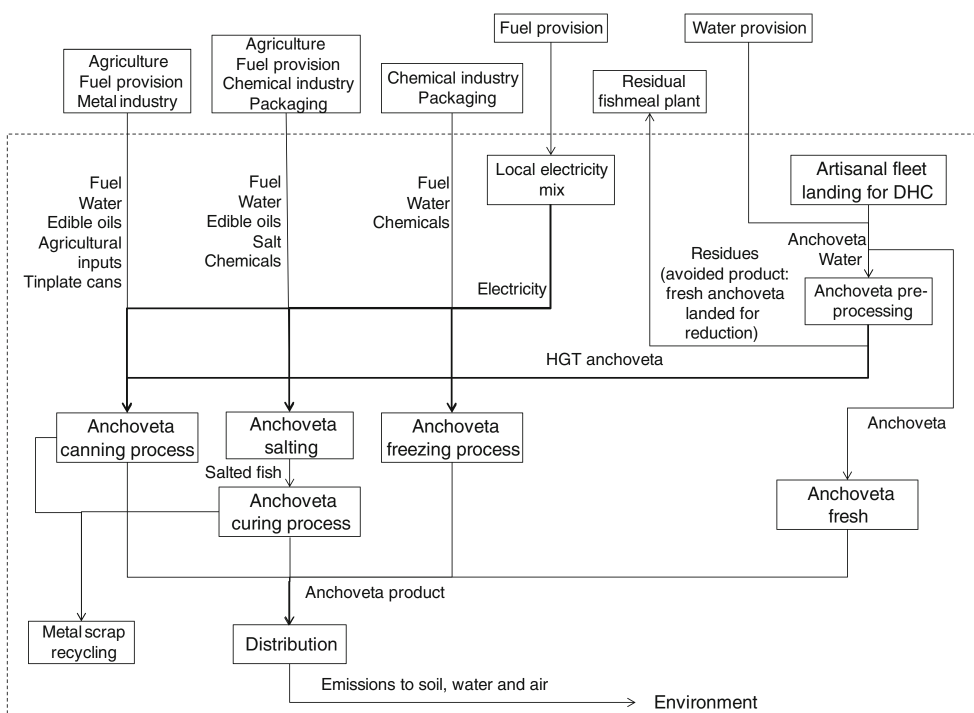


Fig. 3 System boundary for the LCA of the *anchoveta* DHC industries

considered by prorating their estimated fuel consumption into the fuel demand per average landed tonne of anchoveta for reduction and for DHC. Estimation of IUU (7 % of total landings and 23 % of SMS landings) and its associated fuel use demand is detailed in Fréon et al. (2013, 2014b).

2.2 Life cycle inventories

LCI were compiled for the three systems under study, in such a way that the modelled anchoveta DHC products (canning, freezing and curing) are represented according to current practices. The main inventory items included were: fuel and electricity use, refrigerants, water use, packaging and tinplate cans, emissions to air, releases to water, solid residues, chemicals, edible oils and salt, infrastructure (steel, copper wire etc.) and heavy equipment (boilers and compressors, including their construction and maintenance). The system boundary proposed (Fig. 3) depicts canning, curing and freezing as black boxes, although processes are very different within each industry, featuring different resource utilisation, timeframes and associated effluents that were modelled. All of them include intensive energy use, especially freezing (for freezing and cold chambers) and canning (for sterilisation and cooking). Curing generates a large proportion of discards and residues, due to stricter raw material quality requirements.

Primary data collection for fisheries providing the DHC industries is detailed in Fréon et al. (2014b). The most relevant items are fuel consumption, vessel building materials (steel, other metals, wood etc.) and fishing gear. The most impacting items for the DHC manufacturing were energy (fuels and electricity), packaging materials (tinplate and aluminium) and vegetable oils. Key items such as Bolivian soybean oil, electricity (national energy mix), fuel and materials consumed by the fishing fleet and combustion of fuels in industrial boilers were modelled specifically for Peru.

Several fish processing plants were visited in Peru, some of them belonging to vertically integrated fishing companies. The facilities visited were the pilot canning plant ran by the Institute for Fish Technology (ITP) in Lima (ITP 2012), the frozen fish products plant ran by Alimentos Congelados SAC in Ilo,and the anchoveta curing/canning plant ran by Compañía Americana de Conservas SAC (http://grupoconsorcio.com/) in Pisco. ITP cooperates with several industrial producers in product development and certification processes. Operational data from ITP was validated and adjusted to represent industry standards (fuel, water and electricity utilisation per production unit is associated to scale) by means of surveys and field visits made to industrial-scale canning companies (anonymous, personal communication).

Secondary data collected includes industrial average data for liquid effluents from the different fish processing industries (GESTEC 2006; Cristóvão et al. 2012; Bugallo et al. 2013), data for estimating the environmental impacts of refrigerated distribution chains (e.g. Foster et al. 2006; Laguerre et al. 2013; Tassou et al. 2009), energy consumption data for benchmarking of the manufacturing processes (e.g. Hospido et al. 2006) and estimations of the amount of metal scrap generated by the production of tinplate and aluminium cans (Hospido et al. 2006). Moreover, all background processes were taken from the *Ecoinvent* database v2.3 (Ecoinvent 2012).

2.3 Life cycle impact assessment

Among the currently available LCIA methods within the LCA framework, CML baseline 2000 (Guinée et al. 2002) is widely used in fisheries and seafood LCA studies (Parker 2012; Avadí and Fréon 2013) and provides midpoint indicators. The newer ReCiPe method (Goedkoop et al. 2009) integrates and harmonises midpoint and endpoint indicators in a coherent framework. Moreover, ReCiPe extends and complements previous widely used methods (Parker 2012): CML and Ecoindicator 99 (Goedkoop and Spriensma 2001). Thus, ReCiPe was used, complemented with additional indicators and methods when needed:

- ReCiPe is used for midpoint indicators and an endpoint single score, the latter being computed by applying an additional set of characterisation factors to transform midpoints into endpoints, and then a weighting set to calculate a single score (Goedkoop et al. 2013).
- Toxicity characterisation with ReCiPe offers 50, 100 and infinite years. All toxicity models, for instance USES-LCA toxicity model (van Zelm et al. 2009) used by CML and ReCiPe, and the consensus model USEtox (Rosenbaum et al. 2008); feature high uncertainty. Nonetheless, these methods may be used to establish relative trends in contribution to toxicity. Therefore, percent averages of CML and USEtox results were retained.
- Cumulative energy demand (CED) measures the total use of industrial energy (VDI 1997). It is implemented in the homonymous LCIA method (Hischier et al. 2010).
- Biotic resource use (BRU), an expression of the primary productivity consumed by an organism given its trophic level (TL), is not currently formalised into LCIA methods. BRU is calculated by the equation

$$\mathrm{BRU} = \mathrm{PPR} = \left(\mathrm{catch}\big/9\right)\cdot 10^{(\mathrm{TL}-1)} \tag{1}$$

where PPR stands for primary production required and TL for TL of landed species (Pauly and Christensen 1995). BRU is expressed in grammes C per kilogramme. BRU-based discard assessment approaches, as described in Hornborg (2012) and

Hornborg et al. (2012a, b), consist in calculating primary productivity required by species in the discarded fraction of a fishery, and establishing the proportion of threatened species in the discard. Discard indicators could be later used to calculate an index normalised respect to global discards (Vázquez-Rowe et al. 2012b). BRU including discards was calculated for each DHC process, while other discards indicators were not considered because discards are not a pressing issue in the anchoveta fisheries, except during some years.

- Sea use endpoint impact categories, namely the impacts of biomass removal on biotic natural resources (BNR) at the species level ($I_{\mathrm{BNR,\ sp}}$) and at the ecosystem level ($I_{\mathrm{BNR,\ eco}}$), were computed as proposed in Langlois et al. (2014). These indicators express, respectively, the time in years necessary for restoring the biomass uptake of the harvested species, and for regenerating the amount of biomass removed (as an expression of the biotic natural resource depletion in the ecosystem). The indicators are calculated by the following equations:

$$I_{\mathrm{BNR,sp}} = \text{reference flow}\cdot 1/\mathrm{MSY} \qquad (2)$$

(the 5-year average of the total annual catch can be used in substitution of the maximum sustainable yield (MSY) of the stock, if the stock is over-exploited); and

$$I_{\mathrm{BNR,eco}} = \mathrm{BRU}/(A\cdot E_{\mathrm{NPP}}) \qquad (3)$$

where BRU is expressed in tonnes C per tonne, A is the ecosystem area in square kilometres and E_{NPP} is the net primary productivity of the ecosystem in tonne per square kilometre per year. Both $I_{\mathrm{BNR,\ sp}}$ and $I_{\mathrm{BNR,\ eco}}$ are expressed in years.

The software used for computing LCIAs was SimaPro v7.3 (PRé 2012). Both main inputs and outputs of the studied systems—excluding landing of fresh anchoveta, described in Fréon et al. (2014b)—are shown in Table 2.

3 Results and discussion

3.1 Key figures and impact assessment

The anchoveta DHC produce large volumes of mostly residues, which are commonly revalorised by the residual fishmeal industry. By modelling these dynamics, the contribution of residues to lower overall environmental impacts (i.e. ReCiPe single score) of the different industries (manufacturing) was determined as approximately 2 % for canned products, 3 % for cured products, 16 % for salted products and 8 % for frozen products.

Fuel and electricity use are key economic factors in the fish transformation industries (Hospido et al. 2006; Zufía and Arana 2008; Barros et al. 2009; Thrane et al. 2009). Inventory data (Table 2) is consistent with published figures. For instance, reference literature suggests 200 kWh/tonne of frozen fish products (FAO 1994) and 3,579 MJ of thermal energy plus 498 kWh of electricity/tonne of raw fish processed into a canned product (Hospido et al. 2006). The apparent misbalance regarding thermal and electric consumption for canning, which appears when comparing the Peruvian data to similar data in other countries, is due to the fact that Peruvian processing plants often produce large shares of their electricity requirements with thermal generators during peak hours. Curing consumes more electricity than canning due to storage needs (the maturation process during curing takes ~5 months under controlled temperatures). By contrast, canning requires more thermal energy for cooking and sterilisation than curing because cured products do not require such processes. Residence time (in the processing plant) for frozen products was not explicitly accounted for—literature suggests 3.2 days for meat products (Laguerre et al. 2013)—, but anecdotal data collected from plant visits suggest more than one month for Peruvian frozen fish products. The overall associated energy consumption during a production cycle (manufacture plus in-plant storage) of the studied plants was prorated per tonne of product. Water use for canning and freezing has been reported in the order of ~8 and 2.5 $m^3\ t^{-1}$, respectively (Hospido et al. 2006; TASA 2010). Literature data on fish salting and curing is not available as far as we know, so freezing and canning data were used for benchmarking.

Regarding packaging, canned and cured products use tinplate and aluminium cans, which were modelled from *Ecoinvent* metal manufacturing processes assuming a waste production rate of 14 % in the can manufacturing, following (Hospido et al. 2006). Those metal scraps we modelled as fully recycled, yet if no recycling would be present, the additional environmental burden would have been marginal. Moreover, coating substances used in the food can industry were excluded, as well as the modelling of specific vegetable oils used in the fish canning and curing industries (other than Bolivian soybean oil, which was assumed to represent all vegetable oils used in Peru). Olive oil imported from Spain is commonly used by the curing industry; yet Bolivian soybean oil was used as proxy due to lack of data. Spanish olive oil features high environmental burdens, as discussed in (Vázquez-Rowe et al. 2014).

It is noticeable from computed impact categories that freezing products perform orders of magnitude away from canning and curing, which confirm results of other studies performed on other types of food (e.g. Foster et al. 2006). For instance,

Table 2 Aggregated life cycle inventory and impact assessment of *anchoveta* DHC products, per kg of pre-processed fresh fish (after in-plant discards and heading, gutting and tailing)

Inventory items	Unit	Canned anchoveta[a]	Frozen anchoveta	Salted anchoveta	Cured anchoveta[a]
Pre-processing					
Inputs					
Fresh fish	kg	2.00	1.33	3.47	3.47
Outputs					
Fish discards and residues	kg	1.00	0.33	2.47	2.47
Manufacturing					
Inputs					
Pre-processed fish	kg	1.00	1.00	1.00	1.00
Tinplate (cans)	kg	0.13	N/A	N/A	0.19
Aluminium (cans)	kg	N/A	N/A	N/A	0.02
Vegetable oil	kg	0.52	N/A	N/A	0.73
Salt	kg	0.20	N/A	1.04	1.92
Ice	kg	2.00	N/A	3.00	3.00
Fuels	kJ	4,323	N/A	0	76
Electricity	kJ	360	911	0	176
Water	L	10	4	3	16
Outputs					
Other fish process losses	kg	0.71	0	0.08	0.32
Processed fish in product	kg	0.29	1.00	0.92	0.68
Tinplate scrap	g	18.3	N/A	N/A	27
Aluminium scrap	g	N/A	N/A	N/A	2.5
Water emissions (N)	g	1.22	0.08	0.06	1.59
Water emissions (P)	g	0.25	0.04	0.03	0.33
National and local distribution[b]					
Inputs					
Electricity[c]	kJ	0	4,216 (90)	0	N/A
Refrigerant	mg	0	4.17	0	N/A
Transportation (trucks <7.5 t)[d]	tkm	0.350	0.467 (0.067)	0.350 (0.050)	N/A
Outputs					
Refrigerant losses	mg	0	0.41	0	N/A

The sub-inventory related to raw material (fresh fish) is not included

[a] Production average of different presentations and packaging materials

[b] During distribution, 6 days of storage and 4.5 days of in-store display were assumed (Laguerre et al. 2013). No distribution was modelled for cured products, values presented correspond to salted products

[c] Value in parenthesis corresponds to in-store display of fresh chilled products

[d] A factor +16 % was applied to refrigerated transportation to account for additional fuel consumption (Tassou et al. 2009). Values in parenthesis correspond to local distribution

general environmental impacts and specific toxicity impacts associated to frozen products are lower per FU than those of canning (factors 12 and 31) or curing (factors 29 and 82). Nonetheless, losses of the product related to any rupture of the cold chain can generate unexpected additional impacts, likely to occur in a developing country like Peru where electricity supply and some infrastructure are not always adequate. Fresh landed anchoveta has obviously the lowest associated impacts, mostly attributable to fuel use by the SMS fleet (Fréon et al. 2014b).

It is worth noting that the environmental impacts of canned and cured products presented here are based on production averages of the specific production mixes of the studied processing plants, which are believed representative of the national production mix (no national data at such level of detail was available). The ReCiPe single score of canned products, for instance, ranges from 0.37 to 0.83 Pt kg^{-1}, yielding a weighted average of 0.55, whereas the single score of cured products ranges from 0.57 to 5.10 Pt kg^{-1}, averaging 1.35 (Fig. 4).

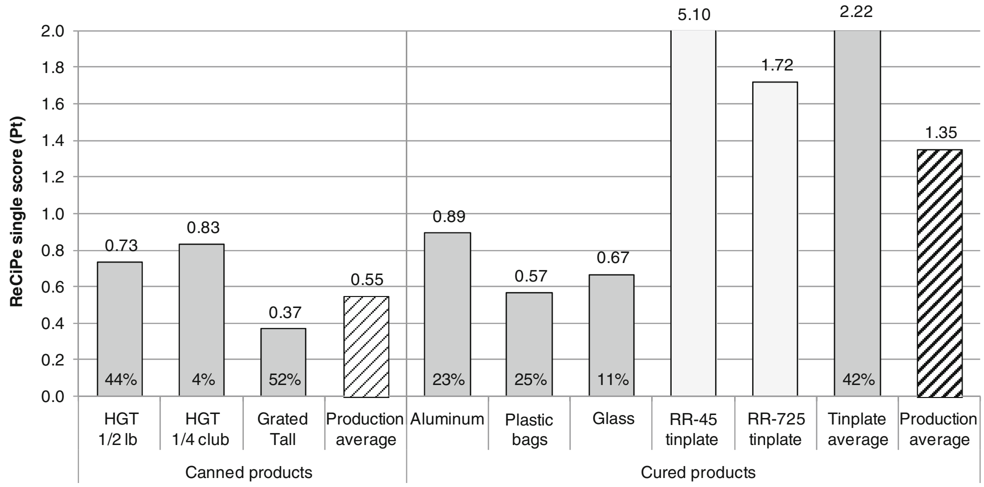


Fig. 4 Relative impacts of various *anchoveta* canned and cured products at plant gate, based on the ReCiPe single-score index; per kg of fish in product. *HGT:* headed, gutted and tailed fish. Percentages indicate contribution to the production mix of ITP and Alimentos Congelados SAC, as representative examples of the Peruvian production mix

LCIA results are summarised in Fig. 5. It is noticeable that, when only manufacturing is considered (Fig. 5a), results for freezing and salting anchoveta (the less energy-intensive industries) are between one and two orders of magnitude lower than those of canning and curing (the more energy-intensive industries) in all impact categories. When distribution over the existing refrigerated distribution chain is included through simulation (Fig. 5b), results for climate change and toxicity increase (170 and 216 %, respectively) for frozen products, due to the additional demand for refrigerated transportation and storage. The implications of expanding the existing fish distribution change are discussed in the next section.

In the agricultural land occupation category, the contribution of vegetable oils to canned and cured products impacts is visible: the difference in contribution between products using and not using vegetable oils reaches three orders of magnitude. It is worth noting that "sea use" (in reference to best known "land use") is not considered in the single score we used (more on this point in the second next section), the same as a few other categories (e.g. water depletion).

Canned products use tinplate cans, while cured products use either tinplate or, aluminium cans, or glass containers. The contribution of packaging materials to overall impacts of these types of products is notable,[3] as depicted in a contribution analysis (Fig. 6a). Such contribution is around 60 % of the ReCiPe single score for both systems.

Between canned and cured products there are important differences in several impact categories. Regarding ozone depletion potential, for instance, the reason for this difference is because the canning industry requires powering autoclaves by means of heavy duty boilers powered by either gas or fuel oils. The curing industry, not entailing sterilisation needs, uses smaller, often gas-powered boilers for other purposes, such as conditioning of cleaning water. Similarly, the differences in the abiotic resource use category are due to the intensive use of oil-powered boilers by the canning industry, unnecessary for the curing industry. Both industries consume tinplate, which contributes with between 40 and 50 % of the abiotic resource use impact. Among all products, the main affected impact categories were climate change, human toxicity and fossil depletion, with different levels of contribution to the overall environmental impacts of each product depending on the distribution strategy used (Fig. 7).

3.2 Modelling the extended fish distribution chain

To distribute fresh and frozen fish (e.g. anchoveta) across Peru, and especially to the highland regions, a cold distribution chain should be in place. Such cold chain would imply refrigerated transport and cold chambers, among other infrastructure. Other distribution chains exist in Peru, such as the poultry products one. Nonetheless, these chains demand less refrigeration and transportation because the bulk of transportation handles live animals, and production hubs are relatively close to consumption centres (MINAG 2012).

To facilitate estimating the additional impacts on the overall environmental performance of anchoveta fresh (chilled) and frozen products that would be caused by a country-wide cold supply chain, we modelled the additional energy demand for transportation and storage and its related emissions, as well as refrigerant leakage from transportation, for both types of products. Infrastructure depreciation was excluded because its contribution was estimated as negligible when prorated by FU. A mean transportation distance between coastal-based producers and target markets in the Andeans has been estimated in 350 km (e.g. the average of Lima-Huancayo and Lima-Huánuco), while local transportation within the coastal region was estimated in 50 km.

[3] ITP has been developing and promoting more economic (and perceived as more environmentally friendly) alternatives to tinplate cans, notably metal–plastic composite flexible—retort—bags (ITP 2007). The use of those materials for packaging of fish products is common in other countries, notably for tuna products (Jun et al. 2006; Poovarodom 2012).

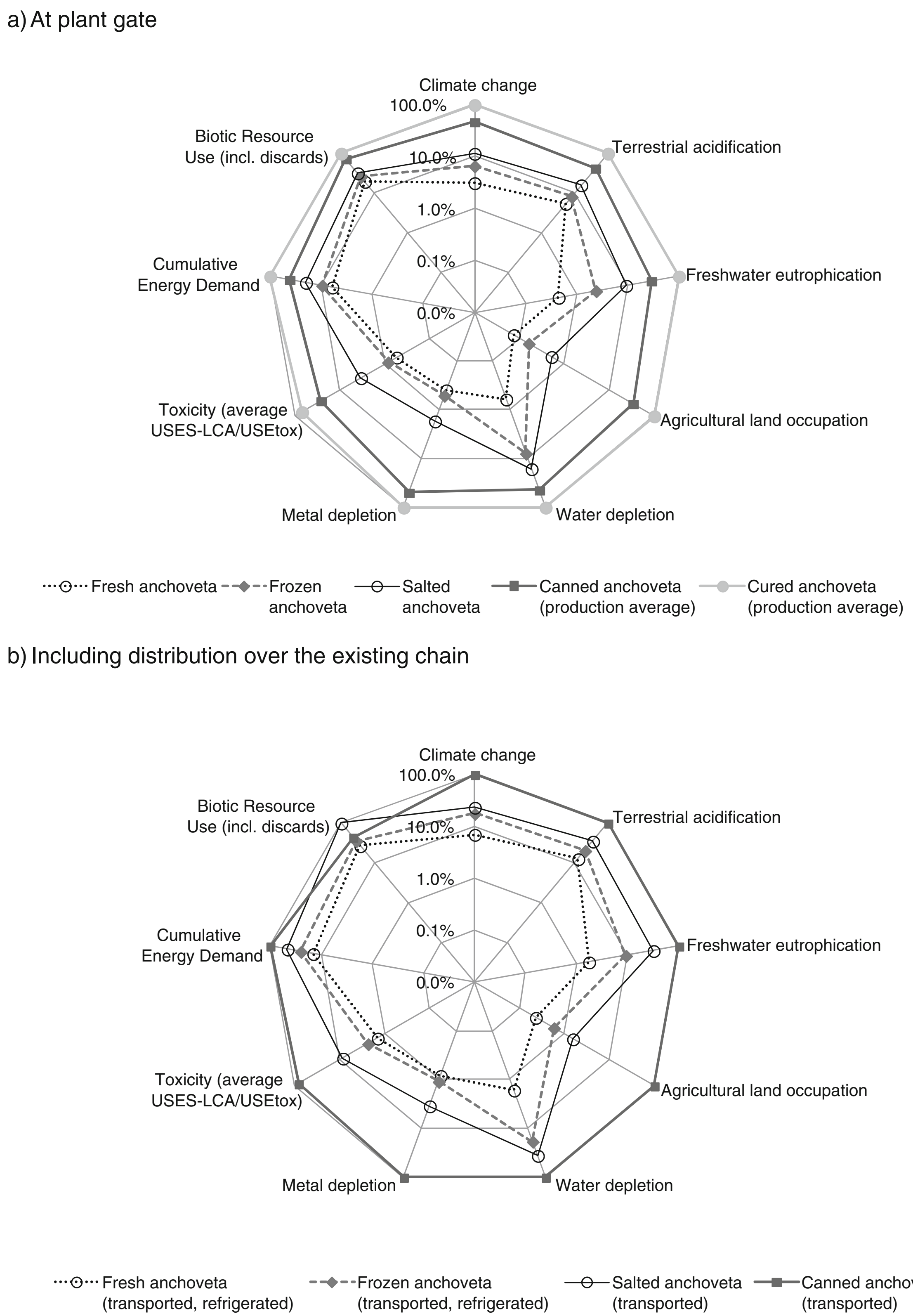


Fig. 5 Relative environmental performance of the *anchoveta* DHC products based on selected ReCiPe LCIA categories (plus Cumulative Energy Demand and Biotic Resource Use), per kg of fish in product

Results, as presented in Fig. 6b, suggest that distribution of chilled and frozen products over a country-wide cold chain would result in higher overall environmental impacts (factors 2.0 and 2.3, respectively) than the existing coastal distribution

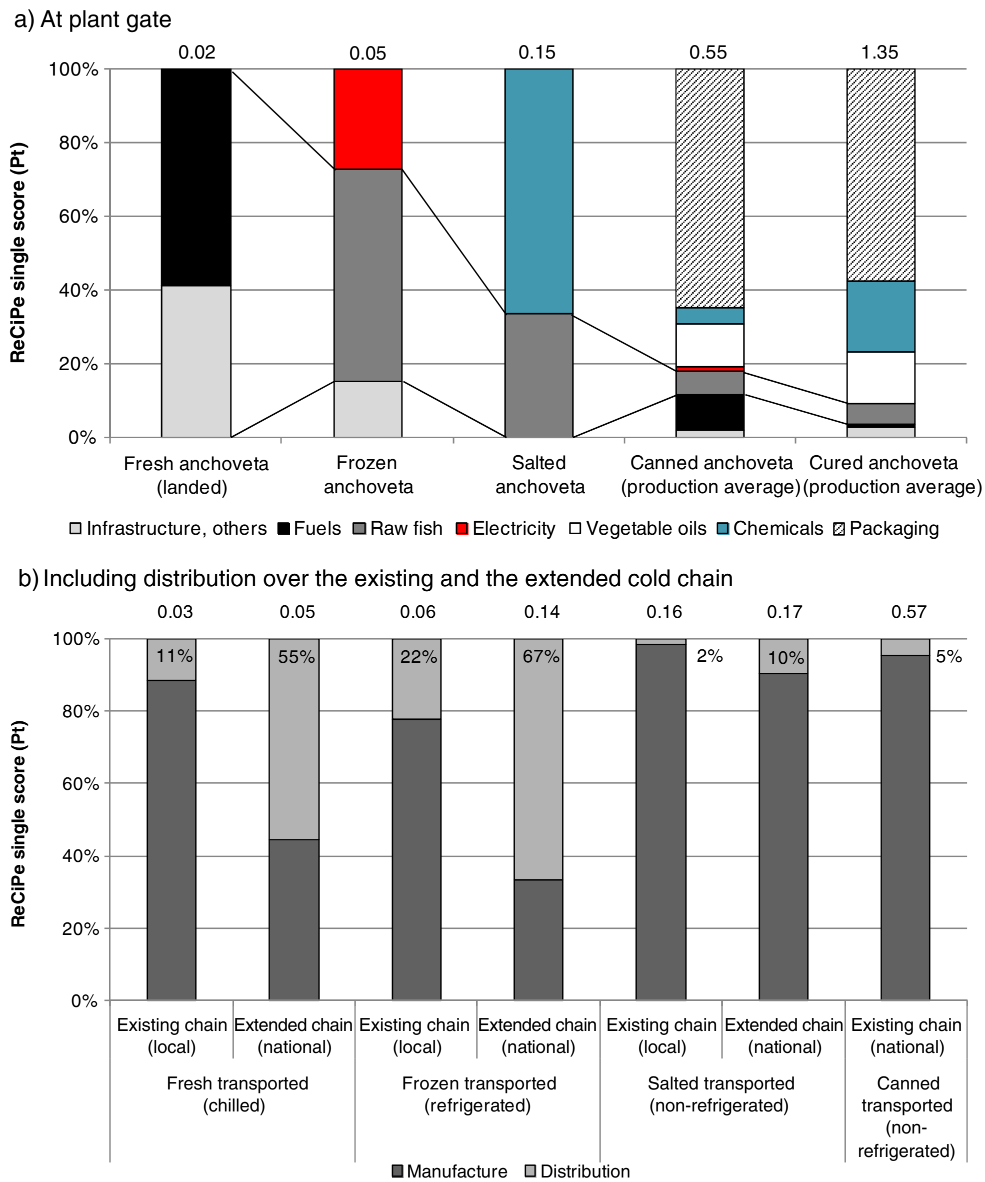


Fig. 6 Relative contribution analysis of the *anchoveta* DHC products based on the ReCiPe single score index (*on top of each column*), per kg of fish in product at plant gate and including distribution. The existing distribution chain services mainly the coastal region, whereas the extended chain intends to serve the national level. Distribution of cured products is excluded because they are destined for export, whereas canned products are already distributed nationally

patterns. Nonetheless, the environmental impacts of these products (including cold transportation and storage) remain way lower than that of canned products, which are distributed and stored without refrigeration. Distribution over the existing and extended distribution chains represents between 2 and 10 % of the overall environmental impacts for non-refrigerated transported products and between 11 and 67 % for refrigerated ones. In this later case, the increase in transport impact related to the extension of the distribution chain is greater for frozen products than for chilled ones. This result is in agreement with a statement in Ziegler et al. (2003), that refrigeration contributed the most to total transport when freezing makes slower transportation possible.

Furthermore, as 52 % of the Peruvian population is leaving along the coast (INEI 2011), the overall impact of the extension of transportation and storage at the national scale would remain minor if the cold chain was extended to the interior of the country.

In previous seafood studies, the additional energy demand of retailing and preserving fresh/chilled and frozen fish products has been estimated in the order of 2.5–11 and 3.2–13 %, respectively (Foster et al. 2006), while another study on frozen cod suggests that 17 % of the impacts can be allocated to the transportation phase (Ziegler et al. 2003). Nonetheless, those fish products have their origin in fuel-intensive fisheries—unlike the Peruvian anchoveta fisheries (Fréon et al. 2014a, b)—and related aquacultures, thus higher energy demands were expected and obtained for distribution in the Peruvian case. Moreover, residence time between processing and consumption of chilled/frozen animal protein products has been estimated in between 11.6 and 14.1 days (Laguerre et al. 2013), yet our interactions with Peruvian seafood producers suggested much longer times

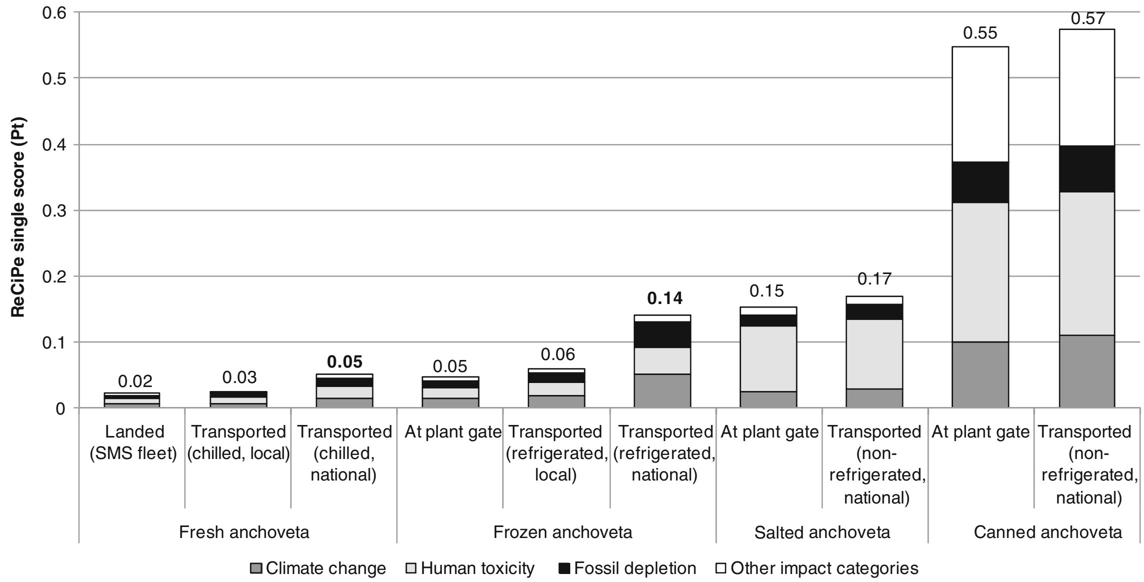


Fig. 7 Contribution of distribution of DHC products, within the coastal region (local) and from the coastal to the highland region of Peru (national), to overall environmental impacts, per kg of fish in product. Canned and salted products do not require refrigeration. Cured products are excluded because they are destined mainly for export

(>1 month in the plant, plus several days in distribution). For the type of transportation vehicles similar to those used in Peru (namely rigid trucks under 7.5 t), refrigerated transportation increases fuel use by ~16 %. Another consequence of refrigerated transportation is the leakage of refrigerant chemicals. Emissions associated with refrigerant leakage have been estimated in the range 17–21 % of transportation emissions, in CO_2 equivalents, assuming a 10 % annual leakage rate (Tassou et al. 2009). Electricity consumption for doored refrigerated display cabinets used in stores has been estimated in 5.6 kWh day^{-1} m^{-1} (Fricke and Becker 2010).

In an attempt to provide figures on the Peruvian DHC products that can be compared with other DHC fish products in other countries, we calculated the climate change/global warming potential (GWP) of all studied products per FU (kg CO_2eq/kg fish in product). This midpoint indicator was retained because it is commonly computed and is usually highly correlated with most other midpoint or endpoint indicators. Comparison with results from other studies is at best limited, due to different system boundaries, assumptions and FU, yet in general terms these indicators provide an easy-to-grasp overview on the environmental performance of Peruvian DHC anchoveta products. GWP figures were calculated for all products except for cured anchoveta, which is not distributed within Peru. Results expressed in kilogrammes CO_2eq at plant gate or including distribution are respectively 0.24 and 0.33 for frozen anchoveta, 0.42 and 0.44 for salted anchoveta, 1.73 and 1.87 for average canned products and 3.70 for average cured product. The latter value is probably underestimated, as the production and transportation of Spanish olive oil was not modelled, but another vegetable oil used as proxy. Once again it is noticeable that national distribution excluding air freight does not dramatically deteriorate the products' environmental performance, as found by other authors (e.g. Ziegler et al. 2007). Our values of anchoveta GWP at plant gate for frozen Peruvian anchoveta (0.24) are one fold lower than equivalent pelagic fish (the Atlantic herring, *Clupea harengus*) produced in Norway and also caught by purse seiners (Ziegler et al. 2007, Supporting information[4]). This difference is mainly due to lower fuel use in Peru than in Norway, which is mainly due to better catch per unit of effort in relation to a higher abundance of the resource and to its closer proximity to numerous landing points (Fréon et al. 2014a).

3.3 Appropriation of net primary productivity and sea use

E. ringens features a generally accepted TL of 2.7 (Froese and Pauly 2011). Nonetheless, other authors have suggested and used a different TL of 3.63 (Hückstädt et al. 2007; Boissy et al. 2011). Following the PPR equation and applying TL=2.7, the BRU of anchoveta is 5,569 g C kg^{-1}. The anchoveta, being a low-TL species, appropriates less primary productivity than other commercially caught and consumed fish in Peru such as horse mackerel and jack mackerel (*Scomber japonicus* and *Trachurus murphyi*, both with TL=3.5 and BRU=35,136 g C kg^{-1}), Pacific hake (*Merluccius gayi peruanus*, TL=4.3, BRU=221,696 g C kg^{-1}), jumbo squid (*Dosidicus gigas*, TL=4.2, BRU=176,099 g C kg^{-1}) and "perico" (mahi-mahi,

[4] Although this work mentions carbon footprint in its title, it makes use of kilogrammes of CO_2 equivalent emissions, which we assume is equivalent to our GWP, as the recent ISO 14067 standard was not yet in use at the time of publication.

Coryphaena hippurus, TL=4.4, BRU=279,098 g C kg^{-1}), according to Fishbase (Froese and Pauly 2011).

Regarding the seas use indicators proposed, fishing anchoveta is less detrimental than fishing other species. The estimated times of compensation of the removal of anchoveta biomass at both the species (stock) and the ecosystem levels are one to four orders of magnitude shorter that in the case of biomass removal of other species commonly harvested for DHC in Peru (Table 3). This result by itself advocates for human consumption of low TL species that is forage fish species rather than piscivorous one. Nonetheless, other considerations than sea use indicators and other environmental impact one must be taken into account when discussing such a complex issue, in particular socio-economic factors that are out of the scope of this study. The same applies to the reason of the low availability of anchoveta for DHC that can be attributable to a combination of numerous factors. Those include regulatory limitations (allowed target supply chain for landings), lower or similar price paid to fishers for anchoveta landed for DHC respect to anchoveta landed for IHC, preferences of consumers driven by alimentary habits and prices of products, lack of a cold chain for fish in Peru (Fréon et al. 2013, 2014a, b; Avadí et al. 2014). More generally speaking, there is an ongoing debate regarding the best use of forage fish at global scale because most of these species (including anchoveta). They can be either harvested for food or for feed then used for feeding terrestrial or aquatic cultivated species. Although the latter display a better fish-in to fish-out ratio than wild fish, they also rely on agricultural systems for their production (Tacon and Metian 2009; Fréon et al. 2010; Welch et al. 2010; Tacon et al. 2011). Such complex issues are being addressed separately by our team.

3.4 Discards

E. ringens forms very large schools, with very low percentages of accompanying fauna, the most common being jellyfish (Quiñones et al. 2013). As a result, by-catch in the anchoveta SMS fishery, consists mostly of jellyfish and other pelagic species, of which the latter are not discarded (Fréon et al. 2014b). Discards are mostly composed of excess anchoveta regular captures or juveniles of this species when their abundance is counter-seasonal, representing in average 3.9 % of landings in the period 2005–2011 (Torrejón et al. 2012). Despite the fact legislation demands that the artisanal fleet can only land anchoveta for DHC (Supreme Decree 010-2010-PRODUCE), a large percentage of their captures reach the fishmeal industry. This is either because the catch spoils before landing for DHC (anchoveta is very fragile, and requires delicate handling onboard) or because it is deliberately and illegally directed for reduction (Fréon et al. 2014a). By contrast, other Peruvian artisanal fisheries for DHC deal with much more scarce stocks of other species than anchoveta, and often feature large percentages of by-catch. For instance, by-catches of the Pacific hake fisheries feature up to 20 species of commercial value, although three to six at a time. The main

Table 3 Sea use indicators of the impacts of biomass removal at the species and ecosystem levels for the main Peruvian species harvested for DHC (Extreme values are highlighted in bold), including landings and fates of landings for the period 2001–2010, per landed tonne

Common name	Peruvian name	Scientific name	Trophic level	Landings (t)[a]		Use of landings[a]				$I_{BNR,\ sp}$[b] (years)	$I_{BNR,\ eco}$ (years)
				Total	DHC	Canning	Freezing	Curing	Fresh		
Peruvian anchoveta	Anchoveta	*Engraulis ringens*	2.7	5,547,772	88,775	70,197	9,099	9,120	358	0.2	21
Pacific hake	Merluza	*Merluccius gayi*	4.3	36,855	36,855		28,466	95	8,294	27	**818**
Horse mackerel	Caballa	*Scomber japonicus*	3.5	77,754	77,754	38,655	17,675	4,673	16,751	13	130
Jack mackerel	Jurel	*Trachurus picturatus*	3.5	158,757	158,757	56,948	17,717	2,233	81,858	6	130
Jumbo squid	Pota	*Dosidicus gigas*	4.2	435,379	435,379	1,509	382,424		51,407	2	**650**
Mahi-mahi	Perico	*Coryphaena hippurus*	4.4	45,815	40,958		14,111		26,847	22	**1,030**
Bigeye tuna	Atún ojo grande	*Thunnus obesus*	4.5	206	203	177	25			**4,848**	101
Skipjack tuna	Barrilete	*Katsuwonus pelamis*	3.8	5,020	4,928	4,312	617			199	20
Yellowfin tuna	Atún aleta amarilla	*Thunnus albacares*	4.3	825	810	709	101			**1,212**	64

[a] Average values for 2006–2010, from PRODUCE statistics (PRODUCE 2012a)

[b] Average total catch was used for calculation, because of maximum sustainable yield (MSY). Estimations were not available, and in Peru most stocks are fully or over-exploited (notably hake), landings exceed official quotas and unreported landings are common. Supporting data: Primary productivity, 1,643 g C m^{-2} $year^{-1}$ for the Northern Humboldt Current System (165,000 km^2), 1,387 g C m^{-2} $year^{-1}$ for the Humboldt Current Large Marine Ecosystem (2.5 million km^2) (Carr and Kearns 2003; Tam et al. 2008)

discard in this fishery is the so-called “pescadilla” (hake of non-exportable size, partly sold on local markets). BRU-based discard figures have been computed for the hake and anchoveta fisheries, and compared in Table 4.

In the post-fishery stage, according to a recent Peruvian legislative action (Supreme Decree 017-2011-PRODUCE), industries processing fish for DHC are allowed to discard up to 40 % of the landings purchased or pre-purchased by the processing plant. Discards by the curing industry are often much higher, even reaching sometimes 100 % of a batch (Echevarría, personal communication, 03.2013).

3.5 Alternative scenarios and sensitivity analysis

A number of hotspots in the DHC processing were identified, yet different ones for the various DHC processes (Fig. 6a): raw fish and electricity for frozen products, salt (brine) and raw fish for salted products, packaging for canned products and packaging and brine for cured products. Therefore sensitivity to those factors was tested, and these scenarios represent alternative productions. By comparing the reference situation with scenarios featuring either a reduced electricity use (for instance as a result of shorter storage in cold and eco-efficiency measures), the best packaging strategy for canned and cured products, and reduced in-plant discards; environmental performance improvements are quantified using ReCiPe single scores (Fig. 8). Performance changes are minor for all cases, except for canned and cured products regarding the best available packaging materials (in agreement with Zufia and Arana (2008) findings) and sizes. Reduction in electricity use and of in-plant discards entail minor overall performance improvements due to the relatively low importance of these factors in environmental performance, which is dominated by packaging (canned and cured products) and fisheries (all other products).

The dominance of packaging impact over fishing in canned product cannot be generalised to other fisheries. For instance Zufia and Arana (2008) found that the fishery impact was always largely dominant (from 67 to 87 %) in eight midpoint impact categories of canned tuna with tomato, although the retained system boundary was larger than our due to the inclusion of home cooking and waste disposal. Once more this result is due to the higher fishing performance of the Peruvian anchoveta fisheries, here compared with an offshore species or group of species (not indicated), probably by a distant purse seiner fleet. By contrast, Vázquez-Rowe et al. (2014) obtained results similar to ours on another small pelagic species (the sardine *Sardina pilchardus*) caught by the Galician purse seiners. Although the system boundary of sardine products was larger than ours, including human consumption and excretion, Vázquez-Rowe et al. (2014) found that the contribution of the canning process itself in the LCA of for most of Galician sardine

Table 4 Biotic resource use (BRU) of discards (including by-catch) from the *anchoveta* and other Peruvian DHC fisheries

Fishery	BRU discards (g C/kg (% of discards))	BRU by-catch (g C/kg (% of by-catch))	Composition of by-catch and discards (trophic level[b] of species used for BRU calculation)	Sources
Anchoveta for DHC	217 (3.9 %)	N/A (N/A)	*Engraulis ringens* (2.7)	Torrejón et al. (2012)
Horse mackerel and Jack mackerel	562 (1.6 %)	N/A (N/A)	Non-target small pelagics including target species juveniles (3.5), jellyfish, other species juveniles and small quantities of sharks.	Kelleher(2005)
Jumbo squid	176 (0.1 %)	N/A (N/A)	Mainly blue shark (*Prionace glauca*) (4.2)	Kelleher (2005)
Mahi-mahi	13,207 (1 %)	82,547 (6.3 %)	Mainly *Prionace glauca* (4.2)	Kelleher (2005) and Gilman et al. (2008)
Pacific hake [a]	30,594 (15 %)	10,118 (6 %)	2007–2010: Pacific drum (*Larimus pacificus*) (5.2), jumbo squid (*Dosidicus gigas*) (4.2), Sharptooth smooth-hound (*Mustelus dorsalis*) (5.1), “pescadilla” or hake juveniles (3.5, lower limit of hake’s trophic level). Different species reported in 2012	CeDePesca (2010), IMARPE (2008) and Salas (2012)
Tuna (long line)	51,069 (29 %)	N/A (N/A)	Mainly *Prionace glauca* (4.2)	Kelleher (2005)
Tuna (purse seiner)	17,920 (5.1 %)	N/A (N/A)	Non-commercial tunas such as bonito (*Sarda chiliensis*) (4.5), dogtooth tuna; rainbow runner, dolphinfish, jacks, shark, billfish, mantas and undersized skipjack and yellowfin and dolphins	Kelleher (2005)

[a] Discard percentage includes 20 % of the by-catch fraction which consists of non-commercial species and individuals (CeDePesca 2010; IMARPE 2008). Average annual by-catch rate for 2005–2012 (IMARPE, unpublished data)

[b] All trophic levels taken from Froese and Pauly (2011)

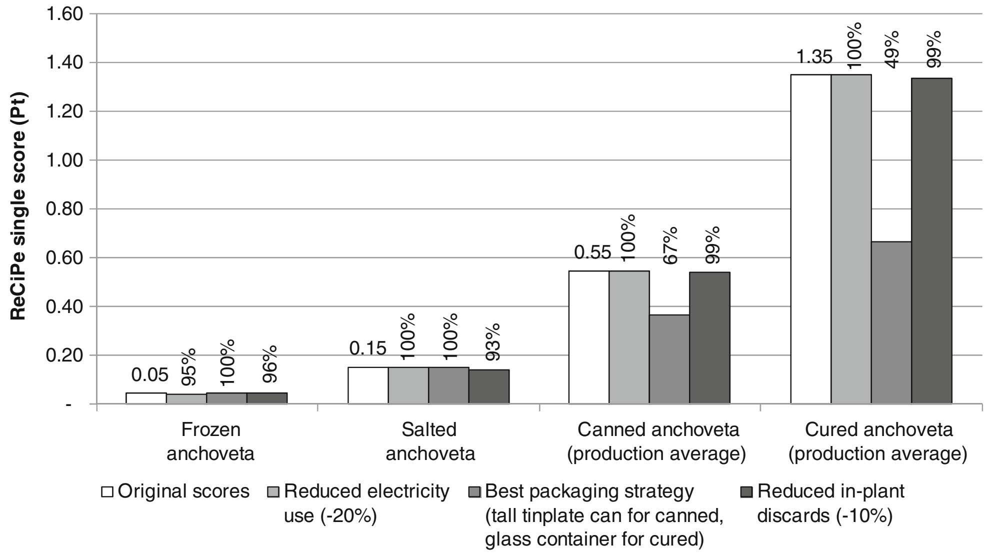


Fig. 8 Performance changes in response to process changes for all studied products, per kg of fish in product

products was dominating in most of the 18 ReCiPe midpoint indicators. When it was not dominating (terrestrial ecotoxicology and water depletion), this was due to the contribution of olive oil used in the product. Furthermore, single score of fried and grilled sardine impacted respectively ~20 and ~12 times more than canned sardine, a result that compares well with our values of ~19 for the single score ratio of canned anchovy to fresh anchovy including existing distribution chains (Galician products were considered transported over a mean distance of 35 km versus 50 km in our case).

To keep anchoveta at a DHC quality level, vessels must insulate their holds and carry ice, practically reducing their holding capacity by at least 30 %. In practice, only a small percentage of SMS vessels feature insulated holds or carry enough ice as to guarantee fish preservation to DHC quality. A scenario where chilled and frozen anchovy would replace more expensive and less environmentally friendly canned and salted product seems promising. These topics are further analysed in Fréon et al. (2014a, b) and Avadí et al. (2014) and lead to some recommendations expressed below.

4 Recommendations

Several aspects of legislation and management could be modified to improve environmental performance of DHC industries, and to promote and support and increase in the consumption of DHC products, especially in the highlands. Some of these aspects are discussed here.

The fact that any DHC industry is allowed to discard up to 40 % of the landings purchased by the processing plant is clearly counterproductive. Such a fixed ratio does not represent the operative features of different processing industries. For instance, freezing and canning have much more tolerance than curing to fluctuations in freshness, individual sizes, and other raw material quality factors (Echevarría, personal communication, Mar 2013). Tolerances should be adjusted to the technical realities of the different industries. Moreover, legislation and enforcement should better make sure that vessels legally allowed to land anchoveta for DHC feature the required hull insulation and have access to the volumes of ice required for maintaining DHC quality.

A more radical measure would be to modify the dual regimes governing industrial and SMS fisheries, in which the former may land only for IHC and the latter for DHC. Fréon et al. (2014a) suggested that all vessels should be allowed to land to either IHC or DHC, betting that big companies would not only be able to control the sanitary conditions of fishing and landings but also would be able and encouraged to develop marketing mechanisms to push forward consumption of DHC products. The SMS fleet, on the other hand, would benefit from legal access to the IHC market. This measure is likely to decrease the proportion of anchoveta discards from the DHC industry, and the proportion of anchoveta caught for IHC that ends up in residual fishmeal plants.

A national cold distribution chain for fresh/chilled/frozen fish should be favoured in case it is socio-economically and environmentally positive and relevant for the communities to be served by it. The potential market for fish in the highland regions must be studied because it is currently underserved or provided by means of heavily environmentally burdened air shipping. Moreover, vulnerable communities should have access to more and cheaper fish products than canned ones to enhance their diets.

5 Conclusions

Limitations in the scope of the presented assessment are due to inherent limitations of LCA in relation to fisheries, such as the

lack of standardised fisheries-specific impact categories, the lack of characterisation of the impacts of certain substances released to the environment (oils and some antifouling substances) etc. (Vázquez-Rowe et al. 2012a; Avadí and Fréon 2013). To partly overcome the lack of standardised fisheries-specific impact categories we presented here quantitative indices of biotic use, sea use and discard.

For the DHC anchoveta industries, it is possible to conclude that less energy-intensive industries (freezing and salting—less refined, plastics-packaged products) are 4 to 27 times less environmentally impacting than the more energy-intensive industries (canning and curing—more refined, metal and glass-packaged products). However, given the underlying motivation of distributing nutritious anchoveta products to vulnerable and often remote communities without proper cold chain, the transportation and storage needs of all these alternative products must be taken into account. For instance, salted and canned products require no cold storage, while chilled and frozen products do. Refrigerated transportation of fresh and frozen fish over long distances and with long storage produces higher environmental impacts than regular. The additional impacts of those activities do not eliminate the environmental advantage of fresh and frozen products over canned products, yet leaving salted fish as the less environmentally burdened. Moreover, consumer preferences also would play a role in the selection of products to promote (e.g. there is no tradition in Peru of consuming cured fish other than salt-preserved, and that is mainly in the highlands), and relative nutritional value may vary among these products. This issue is addressed in ongoing work by our team.

A possible way to soundly improve the environmental performance of canned and cured products would be to prefer less impacting packaging materials (e.g. glass over metal and tinplate over aluminium) and larger formats (i.e. more edible product per amount of packaging material). Nonetheless, the impact of such changes on acceptance by customers must be evaluated prior to decision-making regarding alternative packaging. Cleaner production-related measures, such as diminishing discards and residues, or reducing electricity consumption; only slightly improves the environmental performance of studied products.

In conclusion, an environmental assessment alone does not provide sufficient information for decision makers to decide promoting a subset of alternative products. We suggest a more comprehensive sustainability assessment, including nutritional and socio-economic indicators, should be performed to compare anchoveta and other seafood DHC products.

Acknowledgements This work, carried out by a member of the Anchoveta Supply Chain (ANCHOVETA-SC) project (http://anchoveta-sc.wikispaces.com) is a contribution to the International Join Laboratory "Dynamics of the Humboldt Current system" (LMI-DISCOH) coordinated by the Institut de Recherche pour le Développement (IRD) and the Instituto del Mar del Peru (IMARPE) and gathering several other institutions. It was carried out under the sponsoring of the Direction des Programmes de Recherche et de la formation au Sud (DPF) of the IRD. We acknowledge Francisco Miro, Alberto Salas (ITP) and Pablo Echevarría (Compañía Americana de Conservas SAC) for their support in data gathering.

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